

# On Development of a Performance Measure for Snow-level Forecasts

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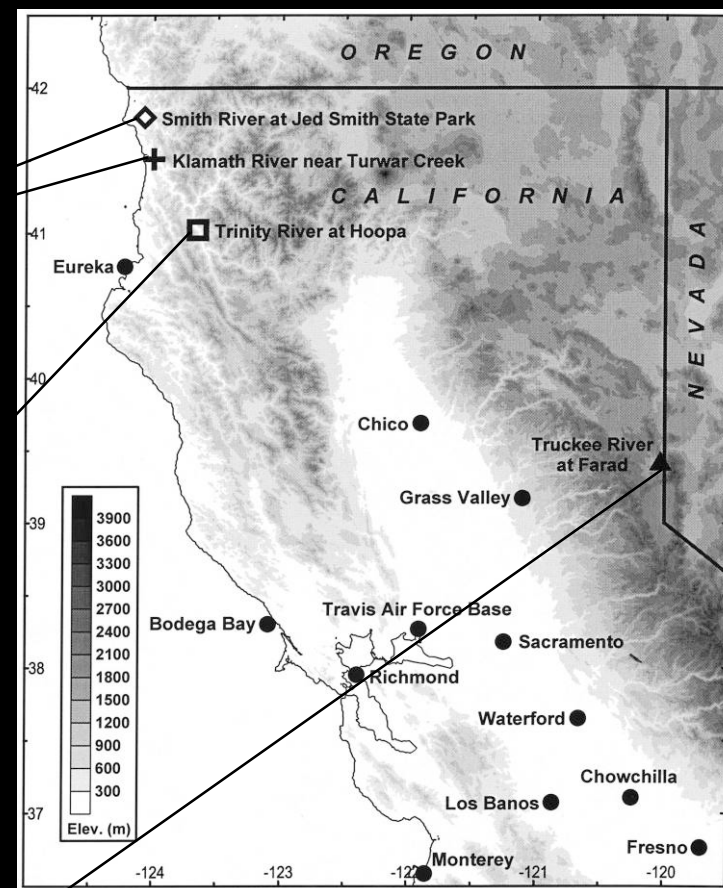
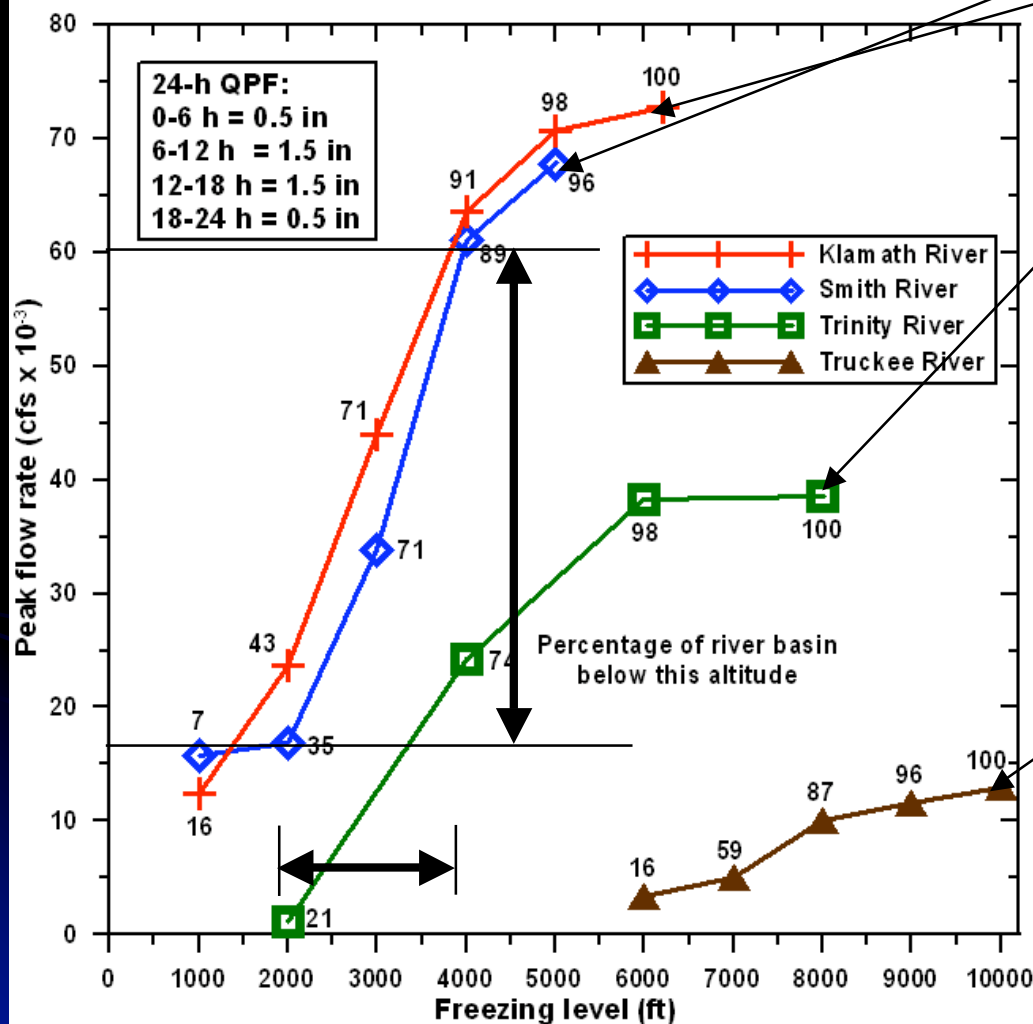
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# OUTLINE

1. Motivation
2. The NOAA/ESRL snow-level algorithm
3. Freezing level forecast performance
4. A new snow-level radar
5. Atmospheric rivers are warm and wet
6. Summary

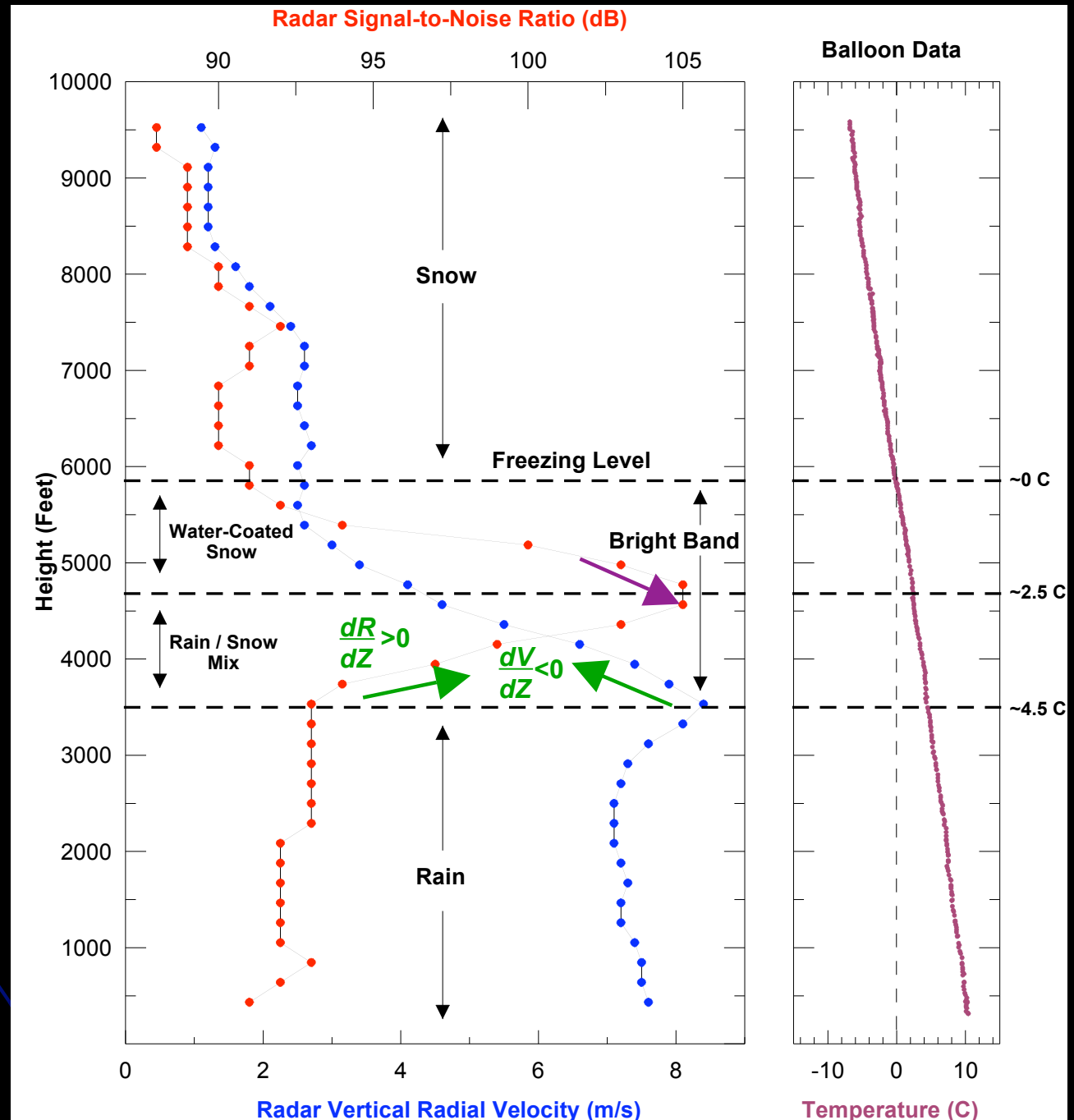
# CNRFC River Forecasting System The sensitivity of watershed runoff to changes in freezing level for a given 24-h QPF

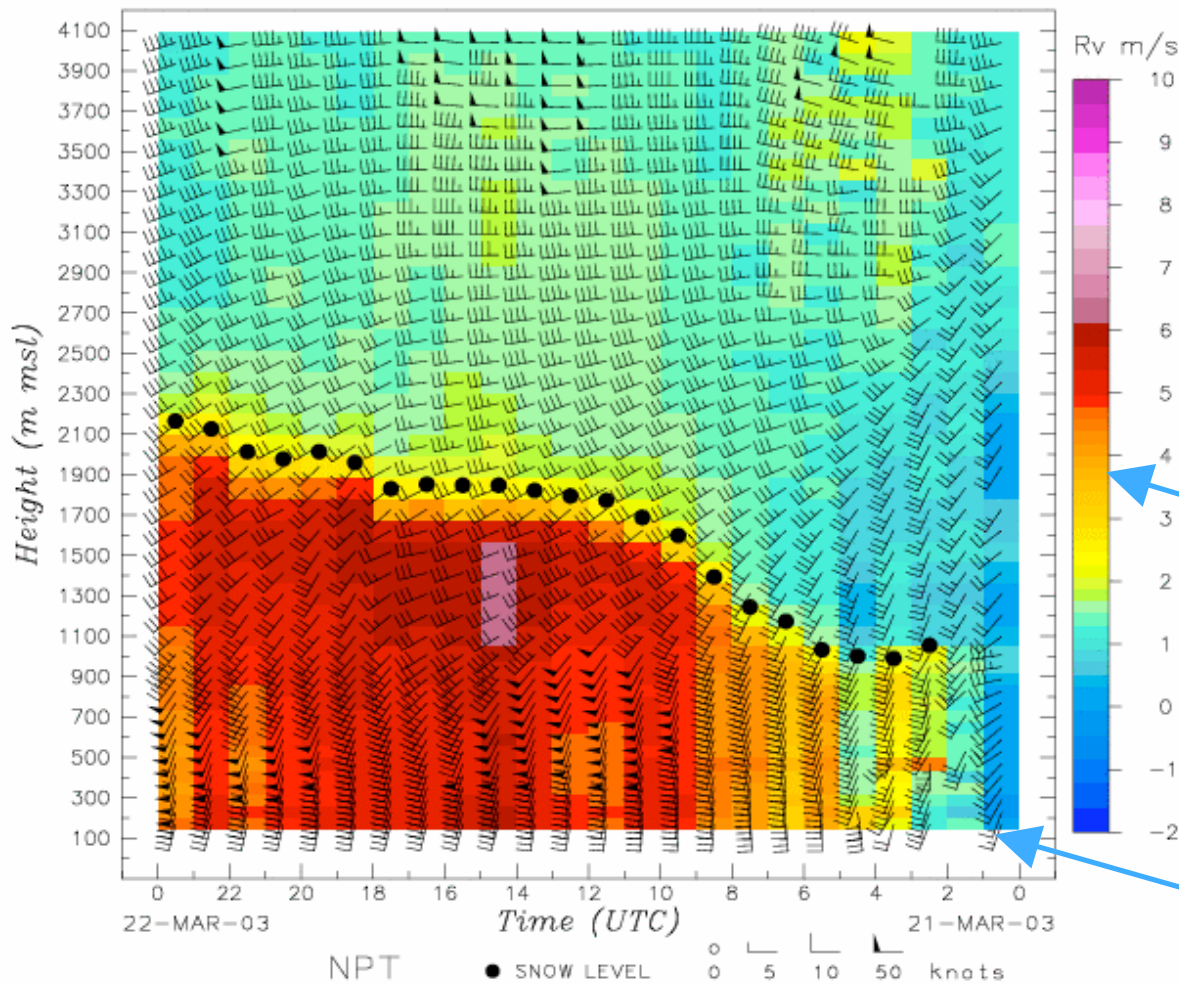


For some of the lower watersheds, a 2000 ft error in the freezing level forecast could more than triple the runoff in the watershed.

White et al. (2002) *J. Atmos. Oceanic Technol.*

1. The algorithm looks for opposing vertical gradients in radar reflectivity and Doppler vertical velocity profiles.
2. If the gradients meet certain threshold criteria, then a bright band is identified.
3. The algorithm finds the maximum reflectivity in the neighborhood of the gradients and identifies the corresponding altitude as the bright band altitude (a.k.a. snow level).





Real-time snow level display available at [hmt.noaa.gov](http://hmt.noaa.gov)

Background displays  
Doppler vertical velocity (Rv;  
positive downward)

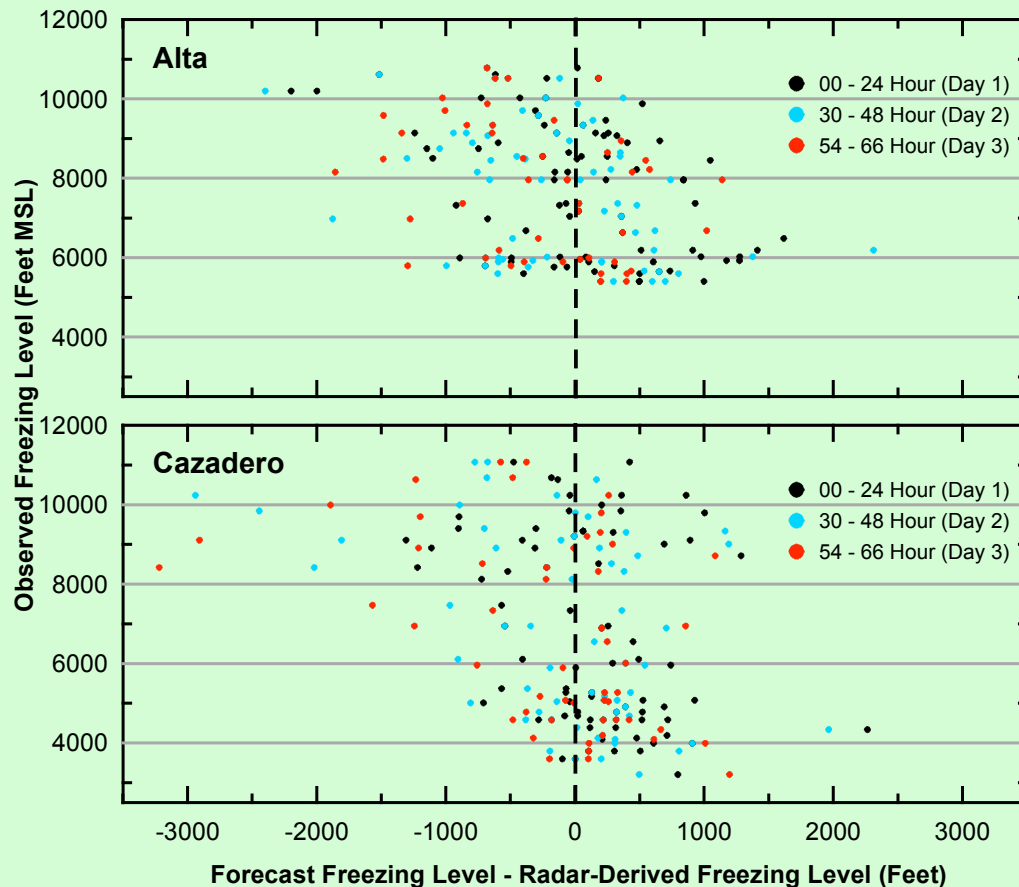
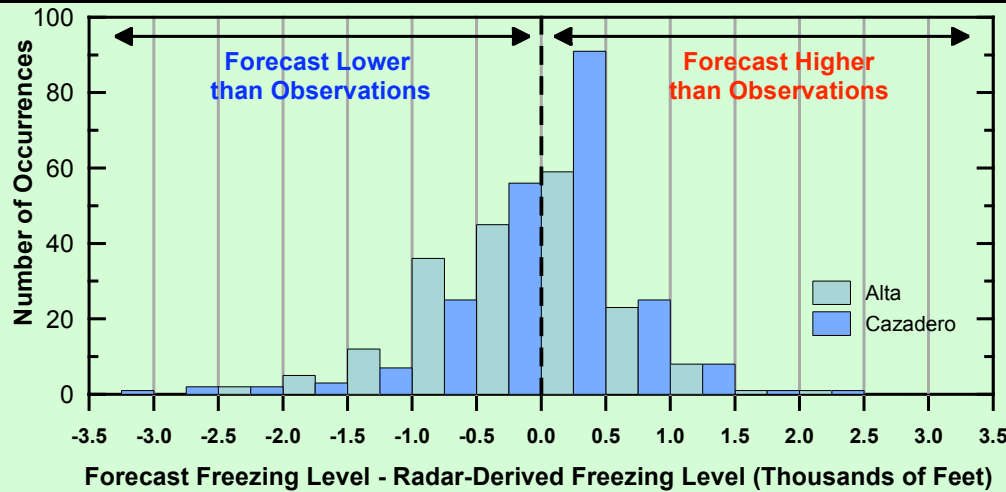
Hourly wind profiles

Table gives snow level in  
English and metric units  
and also provides surface  
temperature (plotted in  
blue font if  $T_s < 0^\circ\text{C}$ )

Time (UTC)	2330	2230	2130	2030	1930	1830	1730	1630	1530	1430	1330	1230
Snow Level (m)	2165	2126	2013	1977	2013	1960	1830	1852	1847	1847	1821	1794
Snow Level (ft)	7101	6973	6602	6484	6602	6428	6002	6074	6058	6058	5972	5884
Sfc Temp (C)	11.05	10.94	10.91	10.76	10.56	10.32	10.23	10.22	10.21	9.81	9.47	9.37

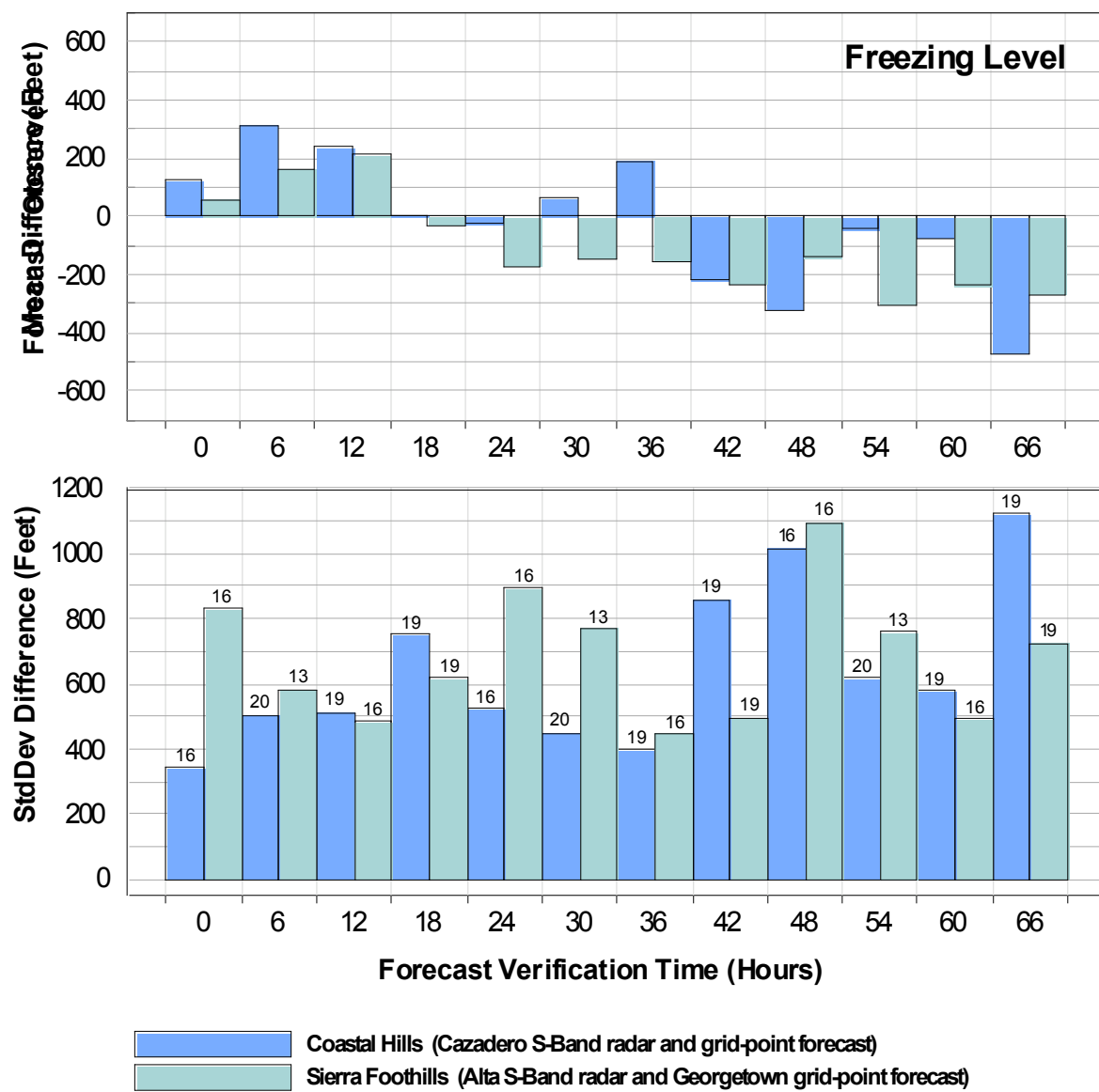
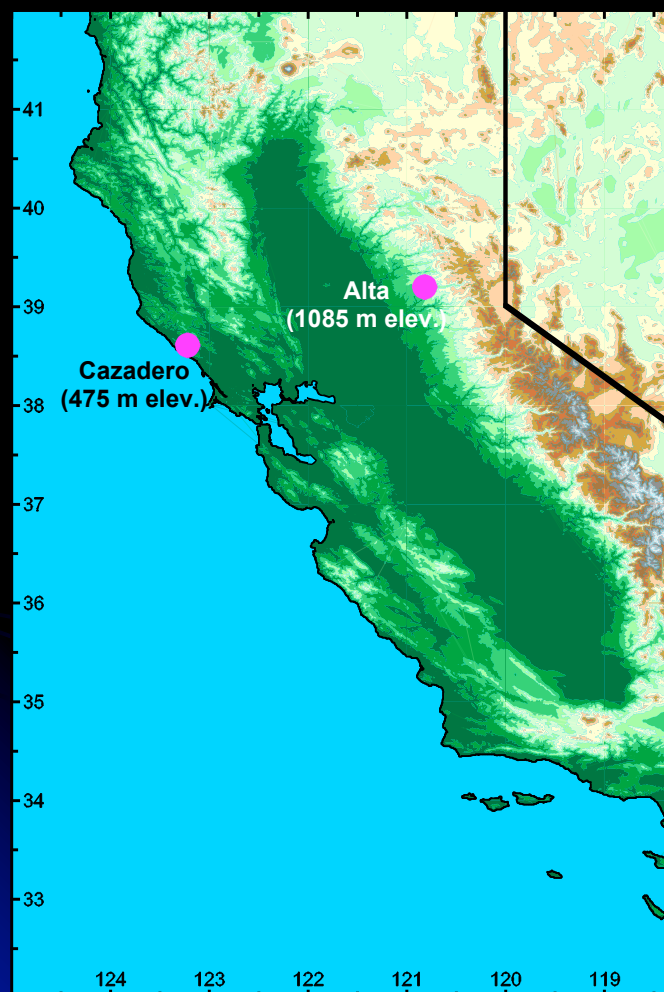
Time (UTC)	1130	1030	0930	0830	0730	0630	0530	0430	0330	0230	0130	0030
Snow Level (m)	1772	1687	1598	1393	1244	1173	1032	1001	989	1054	none	none
Snow Level (ft)	5812	5533	5241	4569	4080	3847	3384	3283	3243	3457	none	none
Sfc Temp (C)	9.40	9.21	8.95	8.86	8.78	8.38	8.16	8.87	8.66	8.49	9.78	10.53

## Snow-level forecast performance

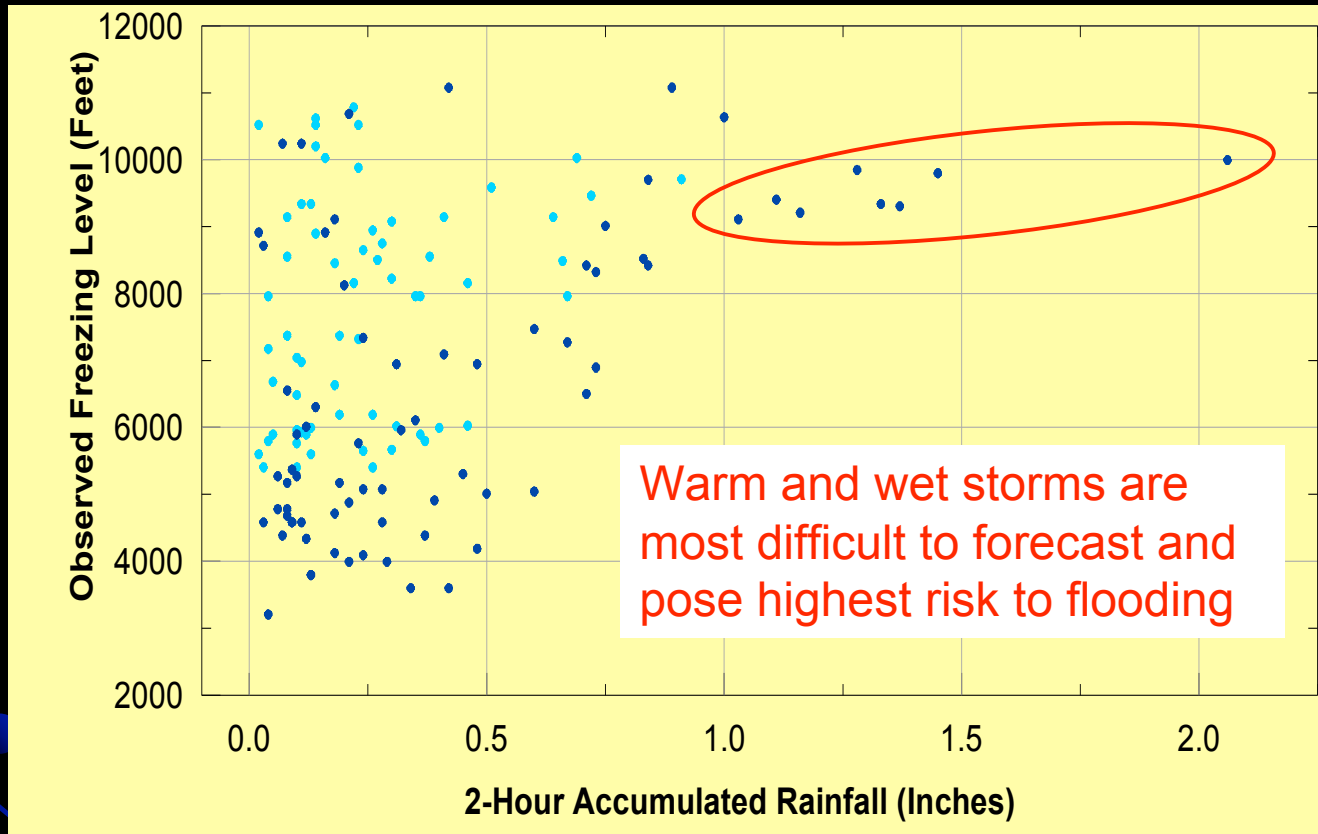


About 15% of forecast bias magnitudes were  $> 1,000$  ft. Of these, most were associated with freezing levels above 7,500 feet, which were forecasted lower than what was observed (by 1,000–3,000 ft).

# Performance as a function of forecast lead time



## Heavier rains occurred with higher freezing levels



The largest freezing level forecast errors were associated with the wettest storms. For example, all >0.5 inch per hour rain rates were observed in the coastal mountains, and these occurred when the freezing level exceeded 9,000 ft.

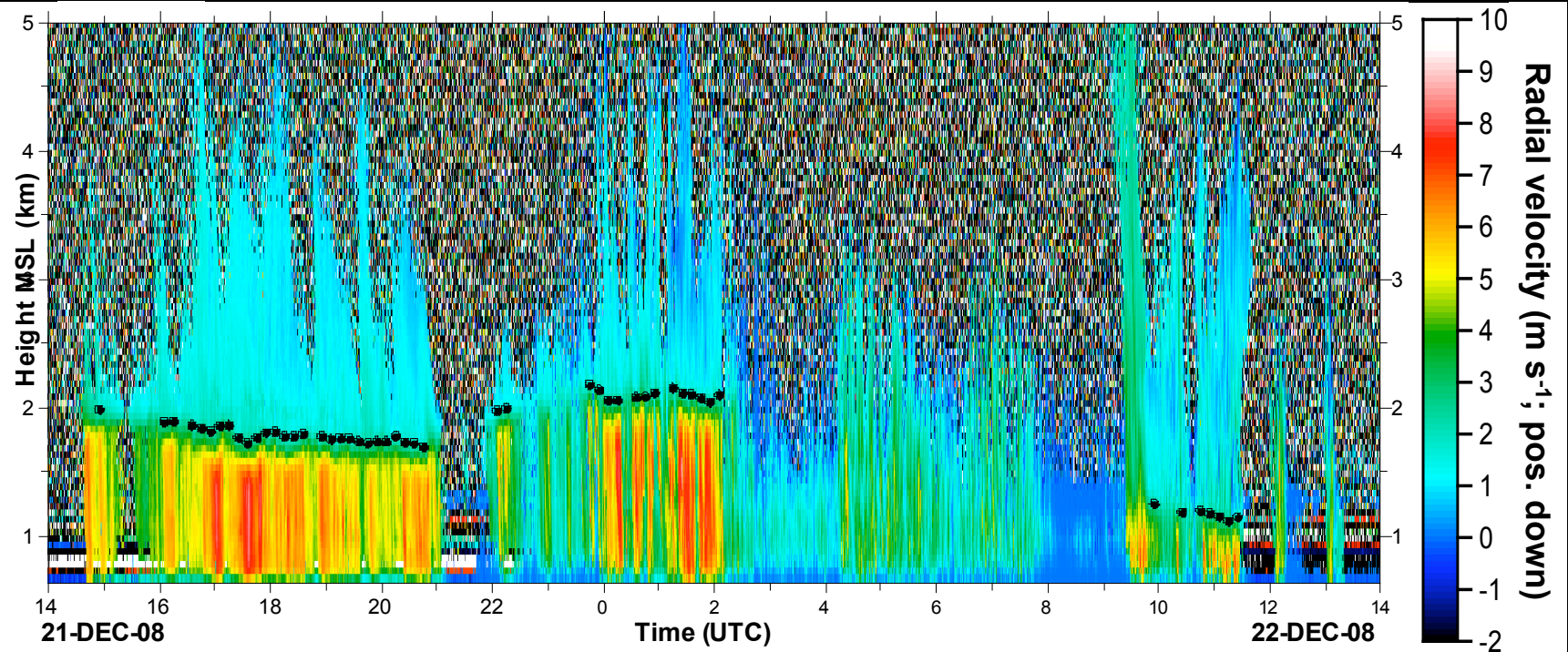
Colfax, CA  
Elev. 636 m



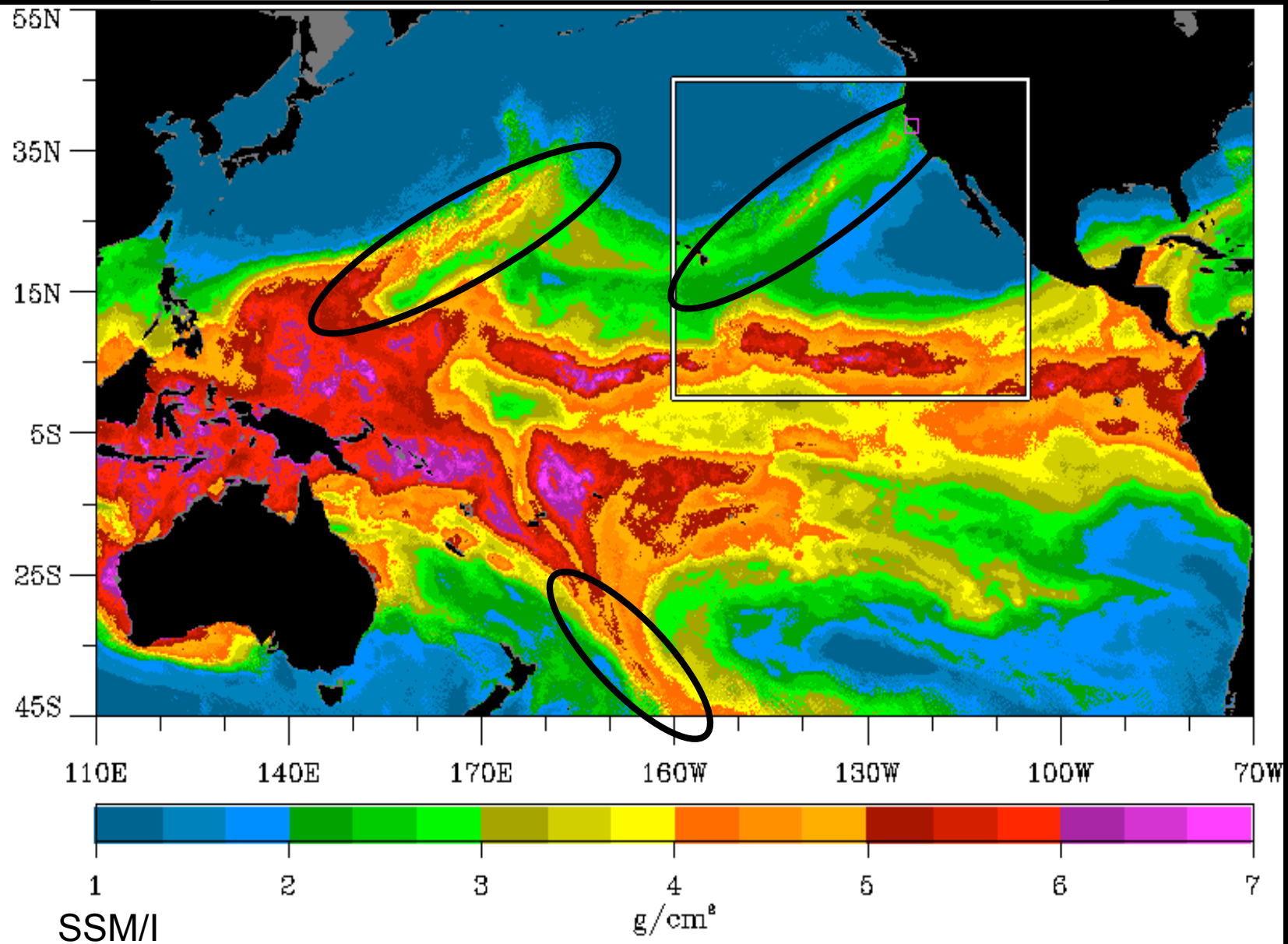
Photo by P. Johnston

## ESRL's New snow-level radar

- Provides proxy snow-level height during precipitation events
- Utilizes FMCW technology to **substantially lower the cost** compared to other radars
- Uses the patented ESRL automated snow-level detection algorithm proven in nationwide field experiments
- Less than 8' diameter footprint
- Low-power requiring minimal infrastructure

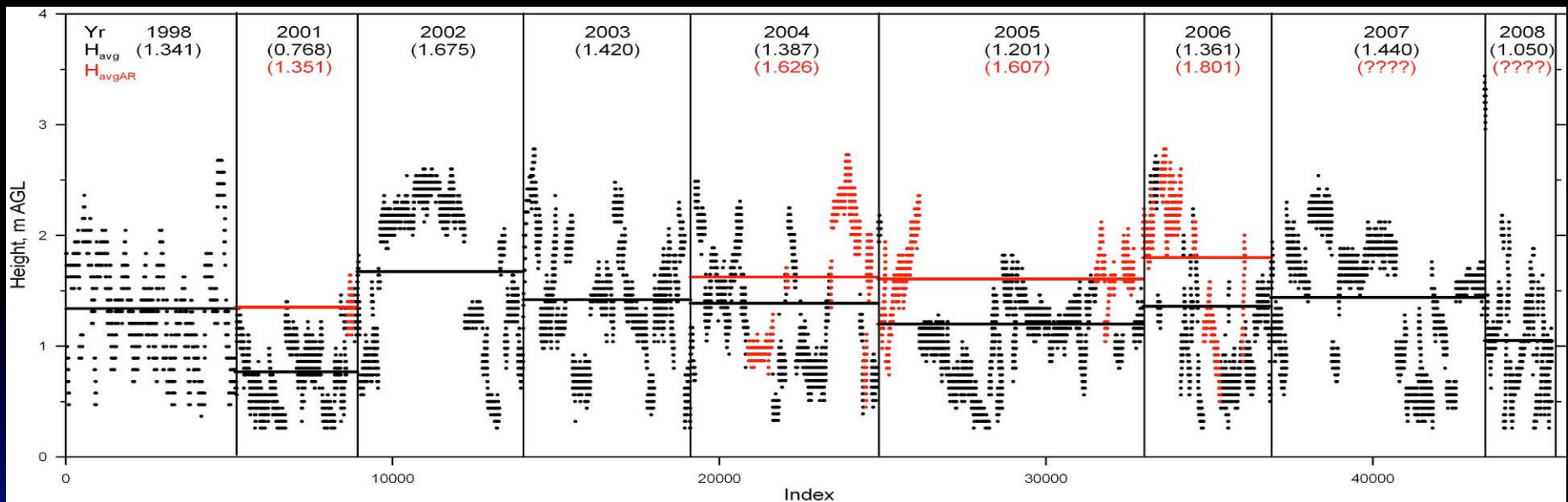


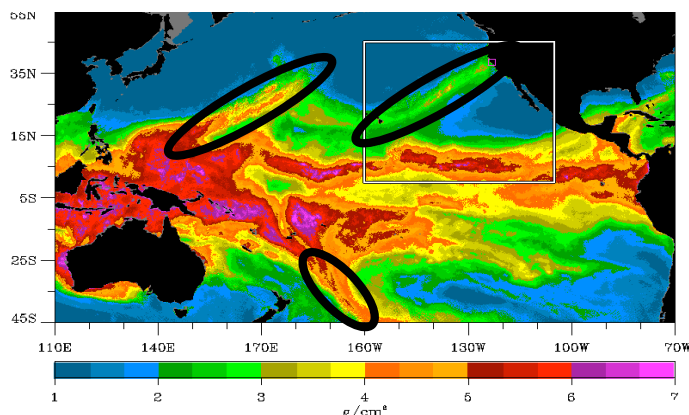
## Atmospheric rivers provide the “juice” for heavy precipitation events



Snow levels measured with ESRL's S-band radar at Cazadero during 4 winters when a GPS receiver was located upstream at the coast averaged 421 m (1380 ft) higher in Atmospheric River conditions:

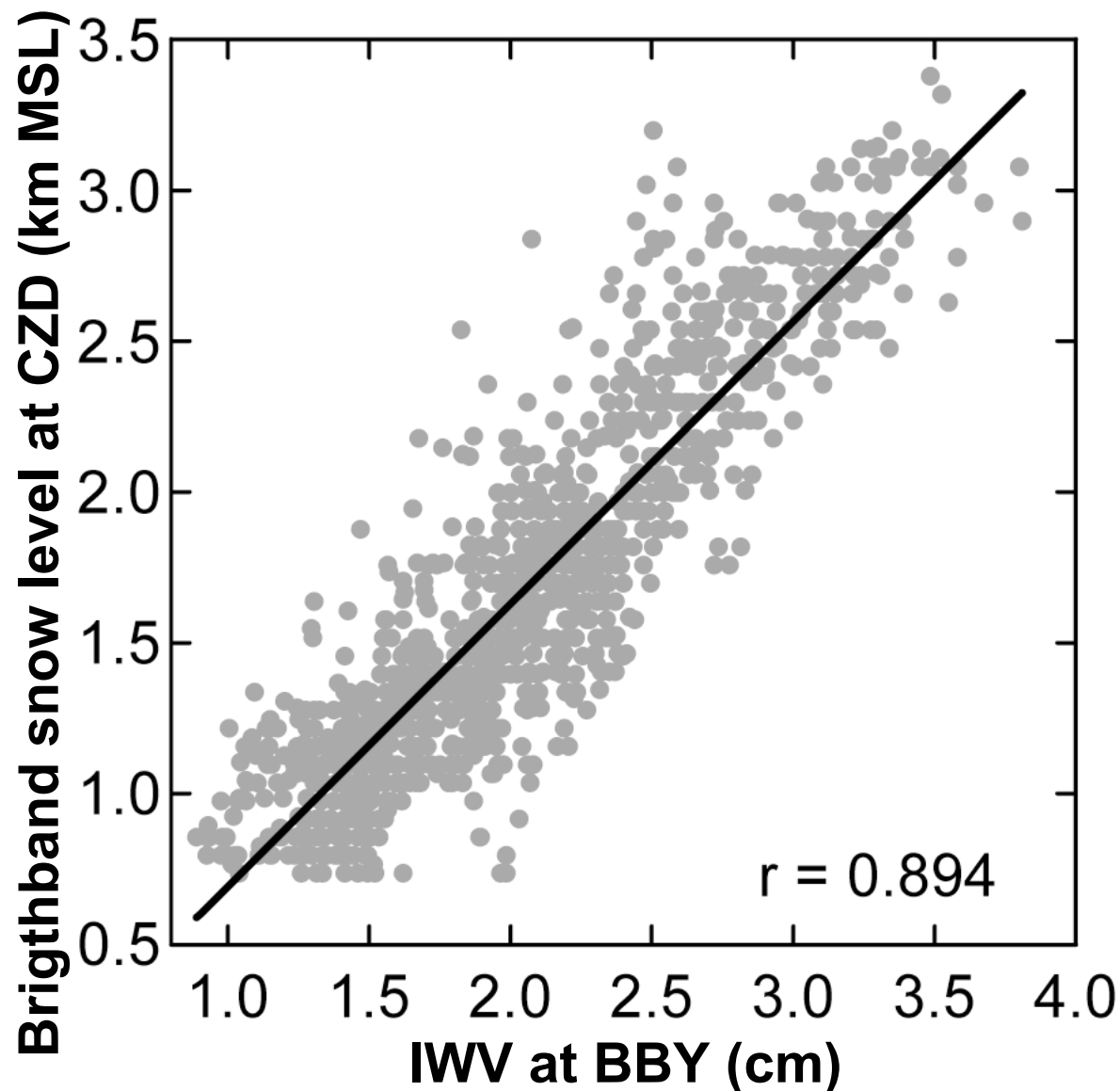
**Warm conditions & more rain = increased flooding**





## ARs are *warm* and *wet*!

- Enhanced moisture available to produce extreme precipitation rates
- High snow-levels increase the potential for flooding in mountainous watersheds

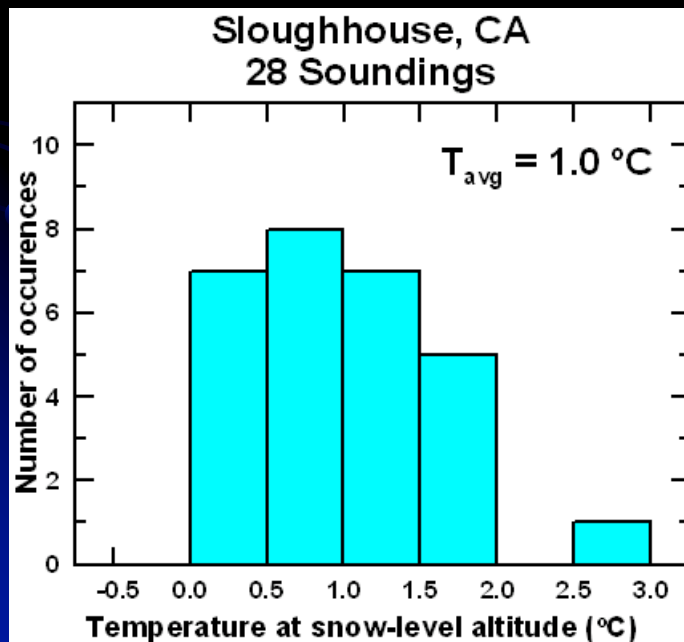
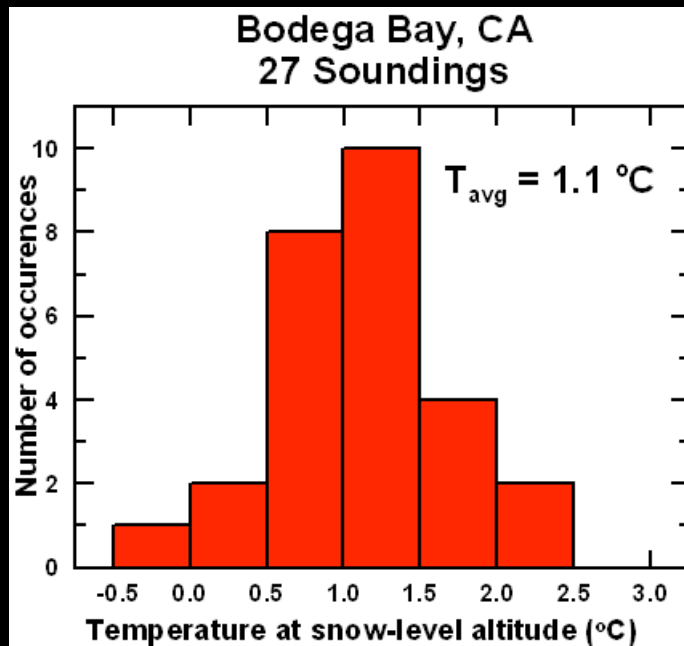


Neiman et al. (2009) *Water Management*

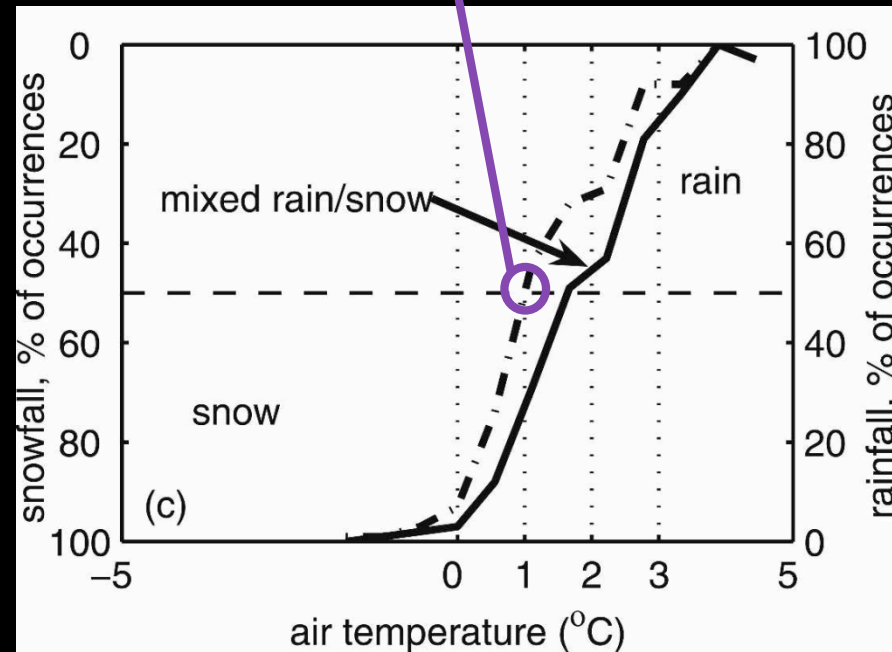
# SUMMARY

- **ESRL has developed a snow-level algorithm for use with vertically pointing Doppler radars.**
- **Despite the importance of the snow level for river and flood forecasting in mountainous regions, there is not an operational performance measure associated with snow level forecasts.**
- **The forecast model used by the CNRFC generally produces a cold bias (i.e., lower than observed freezing levels) at the Day 3 forecast lead time that gradually warms as the forecast lead time decreases.**
- **The overall freezing level forecast bias was small (up to a few hundred feet), but about 15% of the forecasts had errors that exceeded +/- 1,000 ft. Most of these largest forecast errors were associated with freezing levels above 7,500 feet that were under forecasted by 1,000–3,000 feet.**
- **Atmospheric rivers (ARs), narrow regions of enhanced water vapor transport found in many land-falling extratropical cyclones, can produce flooding rainfall intensities, especially in orographically favored regions. ARs are often accompanied by high snow levels, which further adds to the flood risk in mountainous watersheds.**





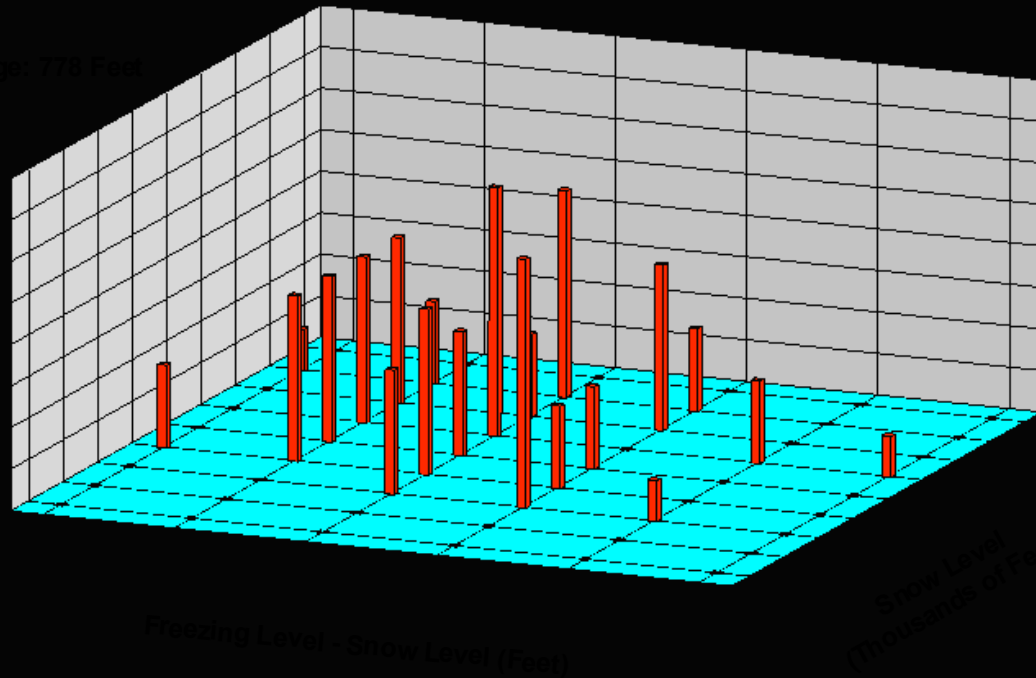
**Surface precipitation is equally likely to occur as snow at  $1.0^{\circ}\text{C}$**



**Lundquist et al. (2008) *J. Hydromet.***

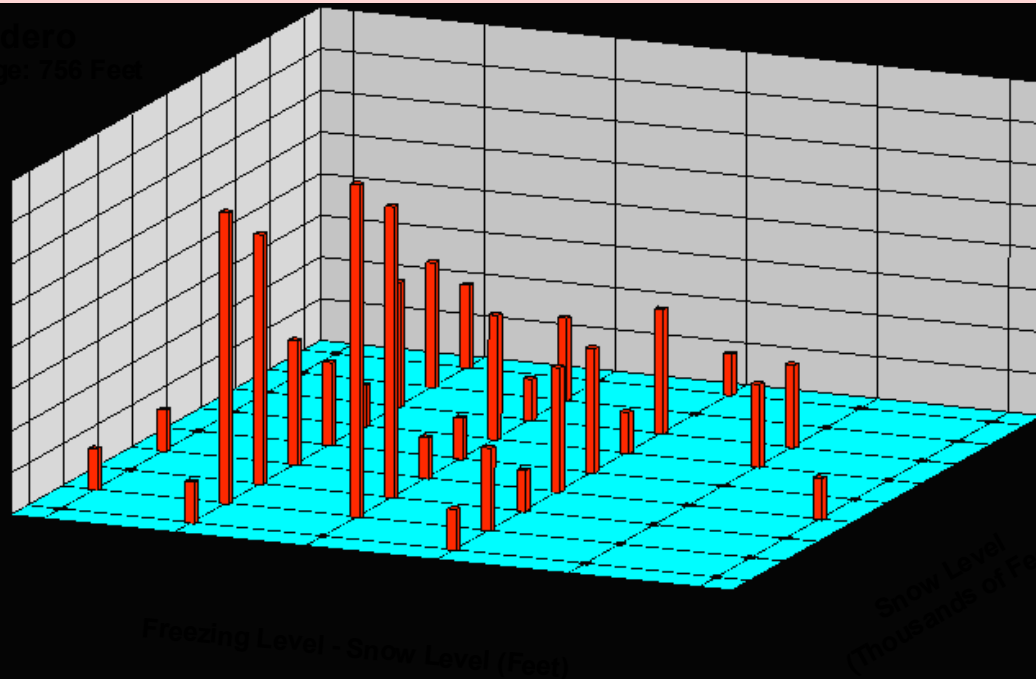
Alta  
Average: 778 Feet

Number of Occurrences



Cazadero  
Average: 755 Feet

Number of Occurrences



The height difference between the freezing level and the radar-derived snow level varies between 400 and 1400 feet, and is not dependent on the height of the snow level. This variability is consistent with the 500 – 1500 foot range that the CNFRC publicly reports as being the snow-level/ freezing-level displacement range.